A Simple Ultrawideband Planar Rectangular Printed Antenna With Band Dispensation

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Abstract—**A compact planar ultrawideband (UWB) antenna with band notched characteristics is presented. Modification in the shape of radiation element and ground plane with two symmetrical bevel slots on the lower edge of the radiation element and on the upper edge of the ground plane makes the antenna different from the rectangular printed monopole. These slots improve the input impedance bandwidth and the high frequency radiation characteristics. With this design, the reflection coefficient is lower than 10 dB in the 3.1–10.6 GHz frequency range and radiation pattern is similar to dipole antenna. With the inclusion of an additional small radiation patch, a frequency-notched antenna is also designed and good out of band performance from 5.0–6.0 GHz can be achieved. Measured results confirm that the antenna is suitable for UWB applications due to its compact size and high performance. Also an approximate empirical expression to calculate the lowest resonant frequency is proposed.**

Index Terms—**Band-notched antenna, capacitive coupling, planar monopole, ultrawideband (UWB).**

I. INTRODUCTION

THE advances in ultrawideband (UWB) systems and applications are progressing at a prodigious rate. Many emerging microwave techniques and applications operate on the UWB frequency spectrum, using ultra short pulses on the order of nanoseconds. UWB systems have become more prominent and attracted attention since US-FCC has assigned the frequency band of 3.1–10.6 GHz in 2002. The primary objective of UWB is the possibility of achieving high data rate communication in the presence of existing wireless communication standards. The use of UWB signals in microwave imaging applications in addition to wireless communications requires suitable antennas as transducers between UWB transceivers and the propagating medium.

Broadband planar monopole antennas have received considerable attention owing to their attractive merits, such as large impedance bandwidth, ease of fabrication and acceptable radiation properties [1]–[3]. Conventional planar monopole antennas need large metallic ground planes perpendicular to the radiation element, and hence are not low profile, which limits their applications in compact systems. In order to reduce the size considerably, a series of planar UWB antennas with microstrip or CPW feeding structures were proposed in [4]–[12].

Ultrawideband (UWB) transmitter can cause EM interference to nearby communication systems such as the wireless local area network (WLAN). Therefore UWB antennas with notched characteristics in the WLAN frequency bands are required and can be found in [13]–[15]. There are various methods to achieve the band-notched characteristics. The conventional methods are cutting a slot (i.e., U-shaped, arc shaped and pi-shaped slot) on the patch [16]–[20], inserting a slit on the patch [21]–[23] and embedding a quarter wavelength tuning stub within a large slot on the patch [24]. Alternate way is putting parasitic elements near the printed monopole as filters to reject the limited band [25], or embedding a pair of T-shaped stubs inside as elliptical slot, cut in the radiation patch [26].

In this paper a simple microstrip fed UWB antenna is proposed with an empirical formula to calculate the lowest resonant frequency of planar monopole/dipole configurations. Symmetrical bevel slots are formed on the radiation and ground patch to cause a wide bandwidth from 3.1–10.6 GHz for UWB applications. The notched band covering the 5 GHz WiFi band is achieved by a small rectangular patch fed by 50 Ω transmission line. The width and length of the patch offer sufficient freedom in selecting the notched band and the approach is capable of shifting the notched frequency with steeper rise in V.S.W.R. The antenna has a compact size of 30 mm × 18 mm × 0.76 mm. The measured 10-dB reflection coefficient shows that the proposed antenna achieves a bandwidth ranging from 3–11 GHz with a notched band of 5–6 GHz. The proposed antenna presents omnidirectional radiation patterns across the whole operating band in the H-plane.

The paper is organized as follows. Section II gives a brief description of the antenna configuration. Section III presents the proposed design method and results of simulation using Ansoft HFSS. Section IV reports on experimental results and Section V concludes the findings of this paper.

II. ANTENNA CONFIGURATION

Fig. 1 shows the geometry of the proposed antenna. It consists of a rectangular radiation patch with symmetrical bevel slots placed on the lower side of the patch and a partially modified rectangular ground plane with symmetrical bevel slots located on its upper side. These slots with dimensions w_1 and h_1 play a significant role in achieving a broad impedance bandwidth. The cutting of slots results in steps on the lower side of the radiation patch as well as on the upper side of the ground plane. The width of the step formed is denoted as s and the gap between the radiation patch and the ground plane is denoted as g. A 50Ω

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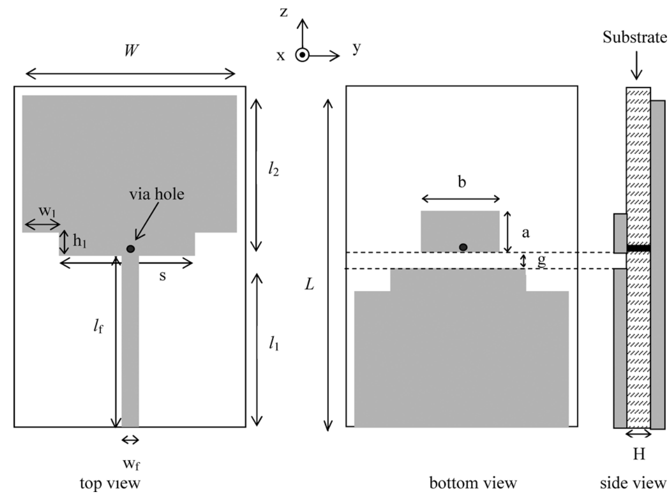


Fig. 1. Configuration of the proposed band notched UWB printed antenna $L = 30$ mm, $l_1 = 14.4$ mm, $l_2 = 14.4$ mm, $W = 18$ mm, $\mathrm{g} = 1.2$ mm, $\mathrm{w}_1 = 3.5$ mm, $\mathrm{h}_1 = 3$ mm, $\mathrm{s} = 11$ mm, $\mathrm{a} = 5.3$ mm, $\mathrm{b} = 7$ mm, $l_\mathrm{f} = 15.6$ mm, $\mathrm{w}_\mathrm{f} = 1.4$ mm, $\mathrm{H} = 0.76$ mm.

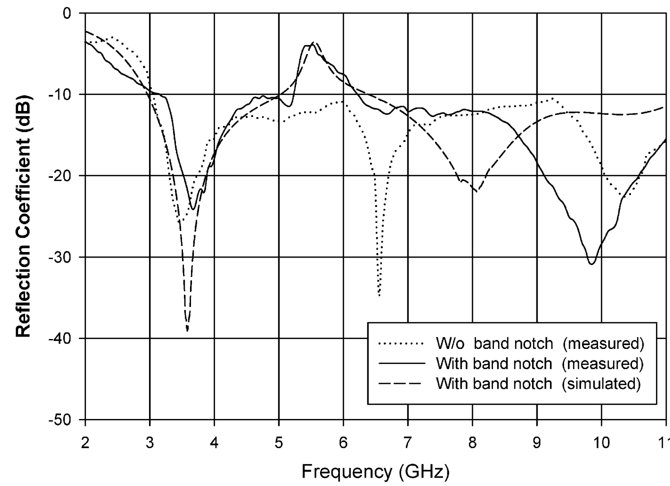


Fig. 2. Measured and simulated reflection coefficients of the proposed UWB antenna.

microstrip line of width 1.4 mm is connected to the radiation patch as the feed line.

It can be seen from Fig. 1 that the rectangular radiation patch and the 50 Ω line are printed on the top side of the substrate while the ground plane is printed on the bottom side of the substrate. A small rectangular patch with dimensions a and b, printed on the bottom side of the substrate is connected to the 50 Ω line through via-hole to produce a notched band in the vicinity of 5.5 GHz and thus prevents the interference with WLAN systems. The antenna was implemented on an inexpensive FR4 substrate with a thickness of 0.76 mm and relative permittivity of 4.4.

A prototype of the proposed band notched UWB rectangular printed antenna with optimal design, i.e., $L = 30$ mm, $W = 18$ mm, $l_1 = 14.4$ mm, $l_2 = 14.4$ mm, $\mathrm{g} = 1.2$ mm, $L = l_1 l_2 + \mathrm{g}$, $\mathrm{w}_1 = 3.5$ mm, $\mathrm{h}_1 = 3$ mm, $\mathrm{s} = 11$ mm, $l_\mathrm{f} = 15.6$ mm, $\mathrm{w}_\mathrm{f} = 1.4$ mm, $\mathrm{a} = 5.3$ mm, $\mathrm{b} = 7$ mm, as shown in Fig. 1, was fabricated and tested and the reflection coefficients were measured using Agilent network analyzer E8363B. Fig. 2 shows the simulated and measured reflection coefficient curves. The measurement confirms the UWB and band-rejection characteristics of the proposed antenna, as predicted in the simulation.

III. Antenna Design

In this section, the antenna covering the full UWB band (3.1–10.6 GHz) is first described. Then the new band notched structure which is equivalent to series LC circuit, is investigated. The effects of changing the geometric parameters of the proposed antenna on impedance, bandwidth and radiation pattern are discussed. The proposed antenna structure is simulated using the Ansoft High Frequency Structure Simulator (HFSS) software, with lumped port excitation.

A. UWB Antenna Design

The UWB antenna design features a gap (slot) between the radiation patch and the ground plane which introduces a coupling capacitance and plays an important role in obtaining UWB behavior. Hence the ground plane of the proposed antenna is also a part of the radiating configuration and current distribution on the ground plane affects the characteristics of the antenna. It is to be noted that the radiation patch, the gap and the ground plane form an equivalent dipole antenna with fundamental resonance, mainly determined by the length of the antenna. It is worth mentioning that closely spaced multiple resonances which are harmonics of fundamental resonance overlap, resulting in ultrawide bandwidth. The size of the gap opening defines the impedance matching and hence by placing bevel slots on the lower side of the radiation patch and on the upper side of the ground plane, impedance bandwidth is considerably enhanced.

Figs. 3 and 4 show the variation of the reflection coefficients with frequency for different dimensions of the bevel slots. It is seen that in the absence of bevels, $\mathrm{w}_1 = 0$ mm, the reflection coefficient behavior at low frequencies is identical to a narrow band dipole with current mainly distributed over the radiation patch and the ground plane. The placing of slots significantly improves the higher band impedance matching as the shaping of the lower edge of the radiation patch has a substantial effect on the impedance matching of printed monopole antennas. The reason is that the slot formed by the lower edge of the radiation patch and the ground plane with a proper dimensions can support traveling waves at higher frequencies. Hence, properly designing the dimensions of the four bevel slots on the radiation patch and the ground plane will enhance traveling wave mode radiation and improve the impedance matching at higher frequency band. However, the ground plane on the other side of the substrate cannot form a good slot with the radiation patch to fully support traveling waves and hence the antenna operates in hybrid mode of traveling and standing waves at higher frequencies. It is also seen that the fundamental resonant frequency is lowered as the bevel slot dimensions are increased. This also contributes to widening the operating bandwidth. The lowering of the resonant frequency is due to the fact that the effective gap between the radiation element and the ground plane is increased as the bevel slots are increased in size. In other words, by properly choosing the dimensions of slots, impedance bandwidth can

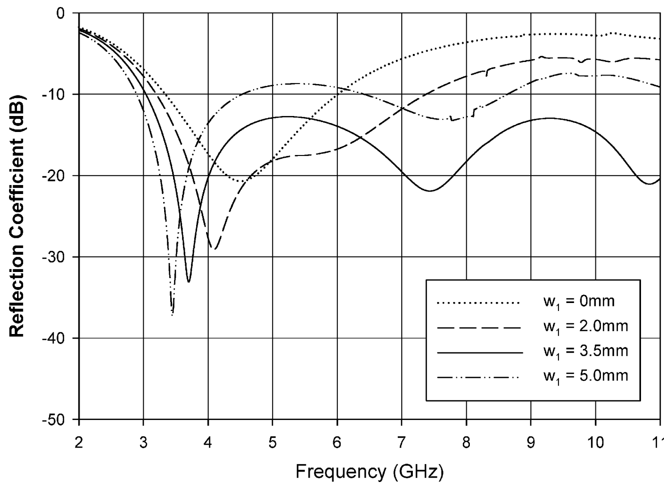


Fig. 3. Simulated reflection coefficients for the proposed antenna of various bevel widths (w_1) with a fixed value of bevel height $(\mathrm{h}_1) = 3\ \mathrm{mm}$. $\mathrm{a} = \mathrm{b} = 0\ \mathrm{mm}$. Other parameters are the same as given in Fig. 1.

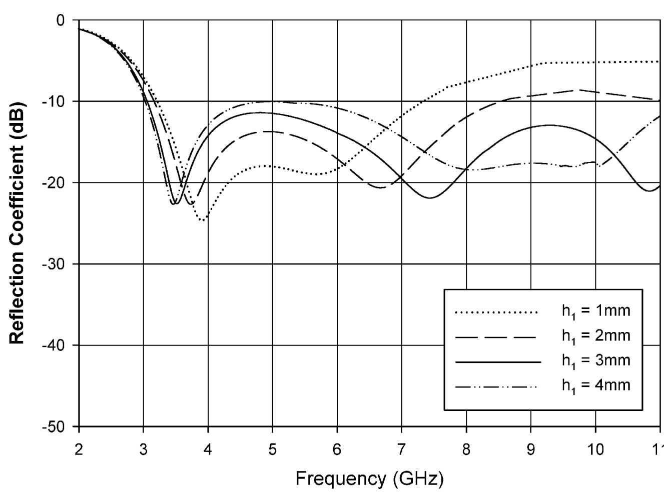


Fig. 4. Simulated reflection coefficients for the proposed antenna of various bevel heights (h_1) with a fixed value of bevel width $(\mathrm{w}_1) = 3.5\ \mathrm{mm}$. $\mathrm{a} = \mathrm{b} = 0\ \mathrm{mm}$. Other parameters are the same as given in Fig. 1.

be enhanced. From the simulated results in Figs. 3 and 4, it occurs when $\mathrm{w}_1 = 3.5\ \mathrm{mm}$ and $\mathrm{h}_1 = 3\ \mathrm{mm}$.

B. Simple Formula for Resonant Frequency

The frequency corresponding to the lower resonance of a rectangular planar monopole can be approximately calculated by equating its area to that of an equivalent cylindrical monopole antenna of same length l and equivalent radius r, as given below [3]

$$2\pi r l = lW \tag{1}$$

where W is the width of the rectangular disc

The lower frequency f_L is given by

$$f_L = \frac{7.2}{l + r + p}\mathrm{GHz} \tag{2}$$

where p is the probe length (gap between the ground plane and the rectangular monopole) of the 50 Ω feed line and l, r and p are in centimeters.

It may be noted that the radiation pattern of these antennas are more like that of a dipole pattern and hence planar printed monopole antenna can be considered as printed dipole of length including the length of the ground plane. It can be seen that in [4], while determining the resonant frequencies of circular discs of different diameters, the height of ground plane is kept constant. But the total length of the antenna configuration is changed with different diameter of circular disc. It is to be noted that change of the dimension of circular disc will not cause a change in resonant frequency as long as the total length of the antenna remains same. Hence it is understood that all reported printed monopoles are in effect dipoles with a fundamental resonant frequency and the height of the ground plane contributes in determining the resonant frequency.

However ultra wide band microstrip-fed planar elliptical dipole antenna has been reported [10]. Further, microstrip-fed semi-elliptical dipole antenna, covering the frequency band from 3.1–10.6 GHz, has been proposed with a small size of dimensions of about one third of the wavelength, instead of half wavelength for the lower frequency [11]. It is found that the length of the antenna is about half wavelength at the lowest frequency of operation, if the dielectric constant of the material of the substrate is taken into consideration.

Hence an approximate general formula is proposed to represent the fundamental resonant frequency of any planar printed radiation configuration with a ground plane.

By equating the area of the planar printed configuration to that of a cylindrical wire of length h

$$2\pi r h = lW \tag{3}$$

since $h = l\sqrt{\varepsilon_{re}}$

$$2\pi r l\sqrt{\varepsilon_{re}} = lW = area \tag{4}$$

$$r = \frac{area}{2\pi l\sqrt{\varepsilon_{re}}} \tag{5}$$

where W and l are the width and the length of the planar element and r is the radius of the equivalent cylindrical wire. $\varepsilon_{re} = (\varepsilon_r + 1)/2$ is the effective dielectric constant of the composite (air-substrate) dielectric.

At fundamental resonance, the length of cylindrical dipole for real input impedance is given by [27]

$$l = 0.48\lambda F \tag{6}$$

where

$$F = \frac{l}{l + 2r}.$$

Thus

$$\lambda = \frac{l+2r}{0.48}. \tag{7}$$

From the above equations, the resonant frequency is given by

$$f_r = \frac{14.4}{l+2r}\text{GHz} \tag{8}$$

where l and r are in centimeters

If l_1 and l_2 denote the length of the ground plane and radiation patch respectively and g is the gap between them, then l can be expressed as $l_1 + l_2 + g$.

Similarly if r_1 and r_2 represent the radius of equivalent cylindrical dipole corresponding to the ground plane and radiation patch, then $2r$ can be expressed as $r_1 + r_2$ (In the case of cylindrical dipole, r_1 and r_2 can be considered as the radius of the dipole arms and $r_1 = r_2 = r$).

Hence

$$f_r = \frac{14.4}{l_1 + l_2 + g + r_1 + r_2}\text{GHz} \tag{9}$$

and from (5)

$$r_1 = \frac{A_1}{2\pi l_1 \sqrt{\varepsilon_{re}}} \tag{10}$$

$$r_2 = \frac{A_2}{2\pi l_2 \sqrt{\varepsilon_{re}}} \tag{11}$$

where A_1 and A_2 are the area of the ground plane and the radiation patch respectively. l_1, l_2, r_1, r_2 and g are in centimeters.

In order to demonstrate the effect of the width of the ground plane and radiation patch on resonant frequency, simulations were done using HFSS by keeping the step width s" constant and the results are shown in Table I.

Table II shows the simulated and calculated resonant frequencies for different ε_r. It is observed that ε_r plays a role in determining the resonant frequency and as ε_r decreases the resonant frequency is lowered and the resonant frequency is increased with increasing ε_r.

Table III shows the comparison between the reported measured resonant frequencies of printed monopoles of different configurations and the calculated results using the proposed formula.

TABLE I
EFFECT OF WIDTHS OF THE GROUND PLANE AND RADIATION PATCH ON RESONANT FREQUENCY FOR THE PROPOSED ANTENNA WITH CONSTANT STEP WIDTH s (s = 11 mm). w_g DENOTES THE WIDTH OF THE GROUND PLANE AND w_r DENOTES THE WIDTH OF THE RADIATION ELEMENT

Width (mm)	Simulated resonant Frequency (GHz)
$w_g = 10$, $w_r = 10$	3.67
$w_g = 10$, $w_r = 18$	3.56
$w_g = 18$, $w_r = 18$	3.50
$w_g = 18$, $w_r = 26$	3.36
$w_g = 26$, $w_r = 26$	3.13

TABLE II
SIMULATED VARIATION OF RESONANT FREQUENCY WITH CHANGE IN DIELECTRIC CONSTANT OF THE SUBSTRATE MATERIAL FOR THE PROPOSED ANTENNA WITHOUT BEVEL SLOTS

Dielectric constant (ε_r)	Resonant frequency (GHz)	
	calculated	simulated
2.2	4.17	3.93
4.4	4.30	4.20
10.2	4.44	4.36

C. The Band Rejection Function for WLAN Band

The UWB system, operating between 3.1–10.6 GHz causes interference to the existing wireless communication systems, for example the WLAN operating in 5.15–5.85 GHz. The band rejection filter employed in UWB RF front-ends avoids the interference but gives complications to the UWB system. To overcome this difficulty, UWB antenna with a band rejected characteristic is required.

The band rejection function of the proposed antenna is achieved by printing a small rectangular patch on the bottom side of the substrate and properly tuning the dimensions of the patch to determine the center frequency and bandwidth of the rejected band. The band notched performance is related to the parameters a and "b" which are the length and width of the rectangular patch. The open circuited small rectangular patch introduced on the bottom side of the substrate is shunt connected to the radiation patch through a via hole. Here, g is the coupling gap between the resonator and the ground plane. The small rectangular patch acts as a resonator and introduces capacitive coupling to offer series resonance band stop function. Since the resonator has an impedance zero at its resonant frequency fr. the main line is effectively shorted at fr and thus no power is delivered to the radiation patch. It is to be noted that capacitive coupled transmission line inductor is less than quarter wavelength at the resonant frequency. The wavelength corresponding to the resonant frequency is given as

$$\lambda_r = \frac{\lambda}{\sqrt{\varepsilon_{re}}}. \tag{12}$$

The area of the rectangular patch with length a and width b can be equated to that of an equivalent cylindrical monopole antenna of height h and equivalent radius r. The average characteristic impedance can be defined as [28]

$$Z_0 = 120\left\{\ln\left(\frac{h}{r}\right) - 1\right\} \tag{13}$$

TABLE III
COMPARISON OF RESONANT FREQUENCIES FOR VARIOUS TYPES OF PRINTED MONOPOLE ANTENNA CONFIGURATIONS

Antenna configuration	Resonant Frequency (GHz)	
	Calculated	Measured
1) Circular monopole with rectangular ground plane [4]	3.14	3.05
2) Elliptical monopole with rectangular ground plane [5]	3.74	3.65
3) Microstrip- fed planar elliptical dipole [10]	2.20	2.27

from (3)

$$2\pi r h = ab \tag{14}$$

from (4)

$$2\pi r a\sqrt{\varepsilon_{re}} = ab \tag{15}$$

where $h = a\sqrt{\varepsilon_{re}}$ and $r = b/2\pi\sqrt{\varepsilon_{re}}$

The inductive reactance offered by the rectangular patch with resistance R_a can be expressed as

$$\omega L = R_a Q \tag{16}$$

where $Q\,(\text{Quality factor}) = 2\pi Z_0/\lambda R$ and R is the resistance per unit length.

Since the rectangular patch resonates at a length approximately equal to quarter wavelength

$$R_a = \frac{R\lambda}{4}. \tag{17}$$

Hence

$$\omega L = \frac{\pi Z_0}{2} \tag{18}$$

and

$$\omega C = \frac{2}{\pi Z_0}. \tag{19}$$

Therefore

$$\text{Inductance}\,(\text{L}) = \frac{Z_0}{4f_r} \tag{20}$$

$$\text{Capacitance}\,(\text{C}) = \frac{1}{\pi^2 f_r Z_0} \tag{21}$$

where f_r is the resonant frequency of the patch resonator.

It may be noted that the capacitance of a rectangular patch primarily depends on the width of the patch, rather than its length. Therefore, when the width of the rectangular patch b is changed, capacitance of the resonator changes with insignificant variation in inductance. Hence it is assumed that $L = L_1$, where L_1 is the inductance when b is changed.

If Z_{01} and f_{r1} represent the characteristic impedance and resonant frequency for the changed width b then

$$\frac{Z_0}{4fr} = \frac{Z_{01}}{4fr_1}$$

and

$$f_{r1} = f_r\frac{Z_{01}}{Z_0} \tag{22}$$

where $Z_0.f_r$ corresponds to resonant frequency for optimal length ($\mathrm{a} = 5.3$ mm) and width ($\mathrm{b} = 7$ mm) of the resonator with inductance L, capacitance C and characteristic impedance

Similarly, when the length of the rectangular patch a is changed, inductance of the resonator changes with insignificant variation in capacitance. Hence, it is assumed that $C = C_1$, where C_1 is the capacitance when a is changed.

If Z_{01} and f_{r1} represent the characteristic impedance and resonant frequency for the changed length a then

$$f_{r1} = f_r\frac{Z_0}{Z_{01}}. \tag{23}$$

Figs. 5 and 6 show the variation of simulated reflection coefficients with different values of a and b. It is seen that as the length and width of the rectangular patch increase, the center frequency of the rejected band shifts to the lower frequencies.

Tables IV and V demonstrate the effect of the length a and width b of the rectangular patch (resonator) on the resonant frequency (center frequency of the rejected band).

Fig. 7 shows the surface current distributions at the pass-band and stop-band. At the stop band, a strong electric coupling (capacitive coupling) occurs at the bottom edge of the resonator

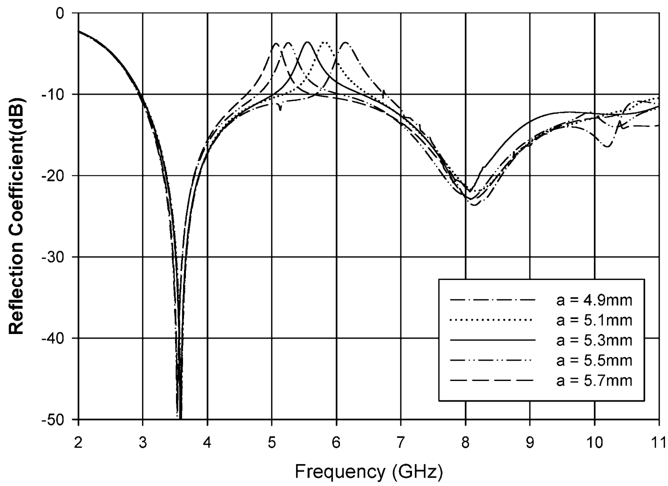


Fig. 5. Simulated reflection coefficients for the proposed antenna of various notch element length a with a fixed notch element width $b = 7$ mm. Other parameters are the same as given in Fig. 1.

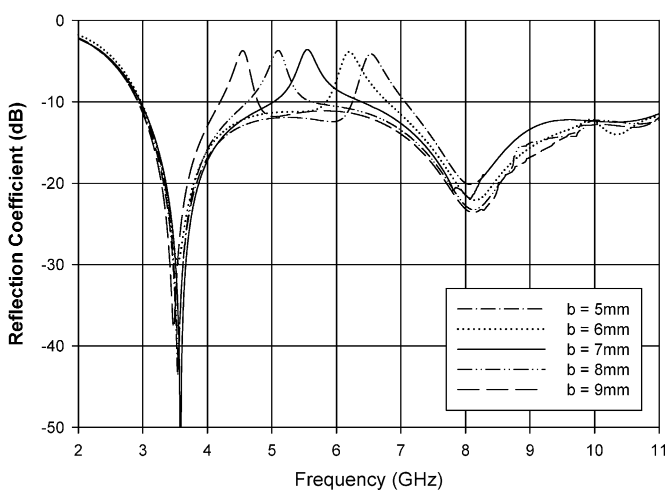


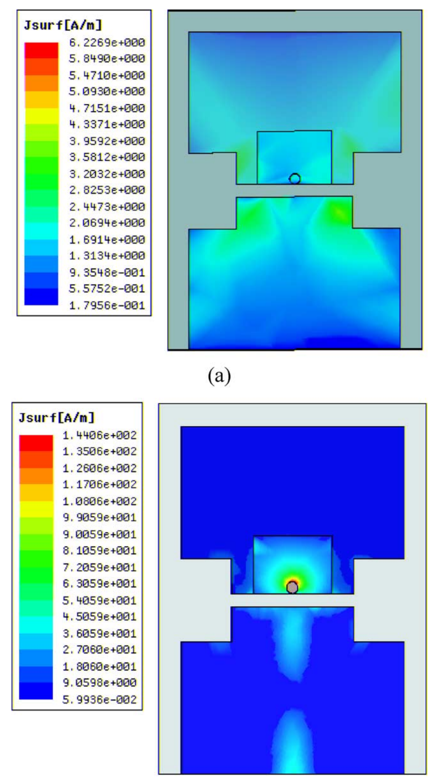
Fig. 6. Simulated reflection coefficients for the proposed antenna of various notch element width b with a fixed notch element length $a = 5.3$ mm. Other parameters are the same as given in Fig. 1.

TABLE IV
EFFECT OF WIDTH OF THE RECTANGULAR PATCH ON RESONANT FREQUENCY OF THE REJECTED BAND FOR CONSTANT PATCH LENGTH $a = 5.3$ mm

Patch width 'b' (mm)	Resonant frequency (GHz)	
	calculated	simulated
5	6.70	6.53
6	6.04	6.19
7	5.50	5.55
8	5.03	5.10
9	4.61	4.55

TABLE V
EFFECT OF LENGTH OF THE RECTANGULAR PATCH ON RESONANT FREQUENCY OF THE REJECTED BAND FOR CONSTANT PATCH WIDTH $b = 7$ mm

Patch length 'a' (mm)	Resonant frequency (GHz)	
	calculated	simulated
4.9	5.80	6.14
5.1	5.64	5.82
5.3	5.50	5.55
5.5	5.37	5.25
5.7	5.25	5.07



(a)

(b)

Fig. 7. Simulated current distribution of the proposed antenna (a) pass-band (at 3.5 GHz) and (b) stop-band (at 5.5 GHz).

patch. Also the surface currents are concentrated at the resonator and the antenna does not radiate. This is analogous to the signal drop across the L-C combination in a series resonant band-stop filter, at resonance. However, at the pass band, the electric coupling does not occur at the bottom edge. The resonator does not work and the antenna returns to the normal operation. It can be concluded that the center frequency of the notch band for the proposed antenna is indeed controlled by the length a and width b of the rectangular patch.

IV. MEASURED ANTENNA PERFORMANCE

Based on the design in the previous section, the proposed band-notched UWB antenna was fabricated and fed by a 50 Ω SMA connector. The measured and simulated reflection coefficient of the proposed antenna from 3–11 GHz is shown in Fig. 2. Measured and simulated results track fairly well.

Fig. 8 shows the measured radiation patterns at 3, 6, and 9 GHz, respectively. It can be seen that the patterns of the proposed antenna present omnidirectional and stable radiation characteristics in the x-y plane (H-plane) over the operating frequency range which are similar to the typical dipole antenna. The x-z plane (E-plane) patterns shown in Fig. 9. demonstrate that at 3 GHz, the pattern is approximately symmetrical. As the width of the radiator is comparable with wave length at higher

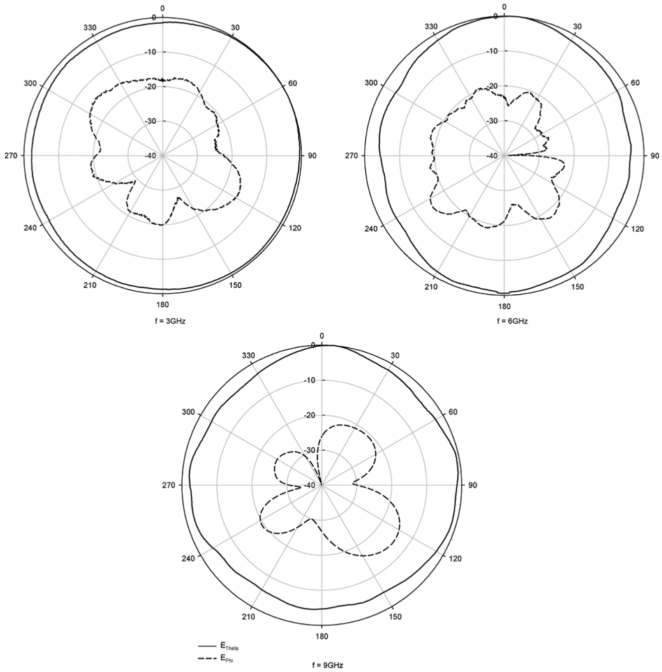


Fig. 8. Measured radiation patterns of the proposed band notched UWB antenna in x-y plane (E_{Theta} and E_{Phi} component).

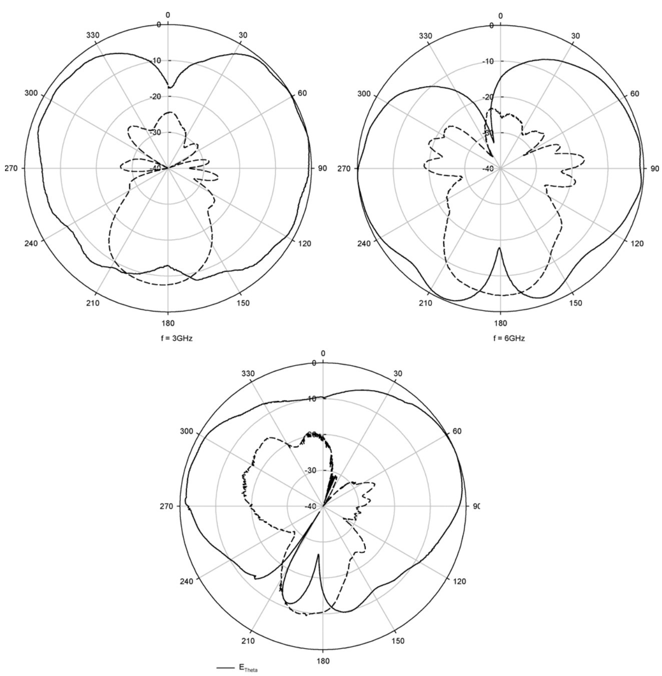


Fig. 9. Measured radiation patterns of the proposed band notched UWB antenna in x-z plane (E_{Theta} and E_{Phi} component).

frequencies, the patterns deviate from symmetry, as can be seen at 6.0 and 9.0 GHz.

Fig. 10 shows the measured and simulated gains of the realized antenna from 3–11 GHz. The figure indicates that the proposed antenna has reasonably good gain over the band of frequencies except for the notched band. Close agreement between measured and simulated results can be found. The measured antenna gain variations are less than 2 dB throughout the desired

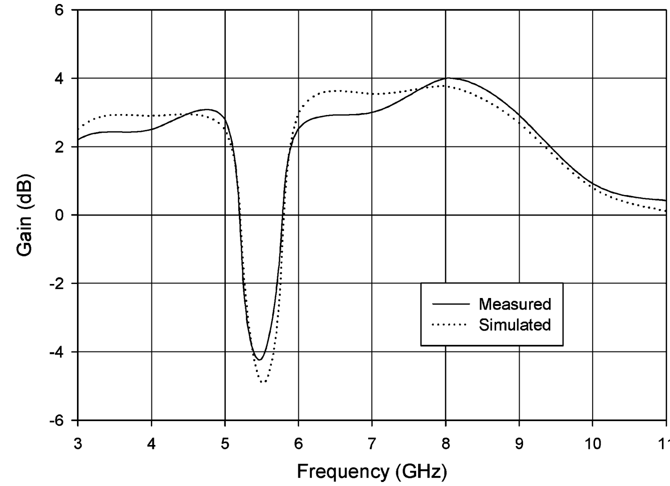


Fig. 10. Measured and simulated gain of the proposed band notched UWB antenna.

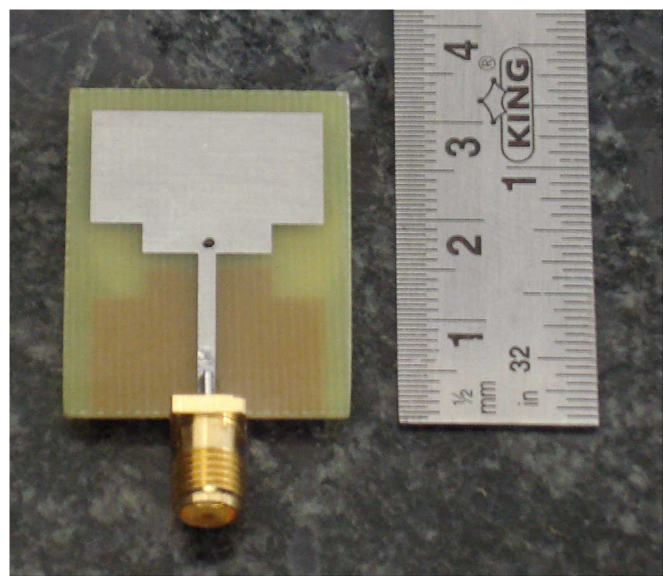


Fig. 11. Photograph of the fabricated antenna.

UWB frequency band and a gain drop of 6–7 dB occurs at 5.5 GHz. A photograph of the proposed antenna when printed on FR4 substrate is displayed in Fig. 11.

V. Conclusion

A microstrip-fed rectangular printed antenna is proposed and implemented for UWB applications. The overall antenna size is 30 mm $\times$ 18 mm $\times$ 0.76 mm. The antenna, compact and simple, has minimum design parameters which have been investigated for optimal design. A frequency-notched antenna is also realized with good out of band performance from 5–6 GHz by including an additional small radiation patch. Besides, by taking the dielectric constant of the substrate into consideration, an approximate empirical formula is presented to calculate the lowest resonant frequency for the planar printed monopole/dipole antennas in general. Study and examination of the formula have shown that various printed geometric configurations reported as planar monopoles can be defined and demonstrated as planar printed dipoles. The present design can easily be extended to dual or triple band-notched antennas. The operating bandwidth of the proposed antenna covers the entire frequency band from 3.1–10.6 GHz.Both simulated and measured results suggest that the proposed antenna is suitable for UWB communication applications and at the same time dispenses the interference with WLAN systems.

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